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Evaluation of the Energy and Comfort Performance of a Plus-Energy House under Scandinavian Summer Conditions

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Abstract

The thermal indoor environment and the energy performance of a plus-energy house are evaluated in the present study. The study case is EMBRACE, a two-storey dwelling of 59 m^2 designed to host a single family. The building includes a semi-outdoor space covered by a glazed envelope, where the thermal environment is also investigated. The house is located in Nordborg, Denmark, where it is undergoing a year-round measurement campaign, of which are presented hereafter the results ranging from June to September 2015.

The thermal environment proved to be satisfactory, with 58 and 15 hours above 26°C respectively in the first and ground floors. In general, the indoor climate was quantitatively better during the heating period (June and September) than in the cooling period (July and August). Overheating did not result to be an issue, which suggests that the installation of a cooling system could have been avoided. The energy balance proved to be positive, with a total of 1563 kWh of electricity produced by the photovoltaic cells installed on the roof, and 333 kWh used by the mechanical systems of the house during the four studied months. The air temperature in the semi-outdoor space frequently reached 2 to 3°C higher than outdoors, which increases the amount of comfortable occupancy hours in this space. The results suggest that the house could perform effectively as a plus-energy house during the whole year.

Keywords - plus-energy house; summer performance evaluation; low temperature heating and high temperature cooling; radiant floor system.

1. Introduction

In the European building sector, the Energy Performance of Buildings Directive (EPBD) has set ambitious goals for the generalization of nearly-Zero Energy Buildings (nZEB) to all new constructions by 2020. Along with this hardening of the regulations arose several new challenges. One of them is the ability of the building industry to achieve nZEB or even plus-energy buildings. Realized examples of such buildings should be studied and showcased as evidence of the feasibility of reaching such high standards. With the current energy crisis and the upcoming depletion of fossil fuels, positive examples of low-energy buildings should be brought forward to lead the industry in this direction.

Another challenge consists in the compliance of realized buildings with the declared energy performance certificates (EPC). Because of differences between the design and the realized building, irregular quality of the building works, errors in the simulations' input data, or lack of control after the building permit issue, the EPC results can differ significantly from the actual observed performance [1].

In relation to these issues, the present study evaluates the energy and indoor climate performance of a dwelling designed as a plus-energy house, EMBRACE, by full-scale measurements. This house was built for the Solar Decathlon Europe competition taking place in July 2014 in Versailles, France. The building was then disassembled and transported to Nordborg, Denmark, where it now stands in a thematic park open to visitors. Because of the short time-span allocated to its construction, which made changes in the building works inevitable, and the several assembly/disassembly processes undergone by the house, the energy and indoor climate performance of EMBRACE could differ significantly from the claimed design goals. For these reasons, the house is undergoing a year-round measurement campaign which aims at verifying the energy and indoor climate performance of the actual built house. This methodology is similar to the one adopted by Kazanci and Olesen [2], who previously studied another plus-energy house under different heating and cooling strategies.

It should also be noted that the EMBRACE house is a prototype built to fit with two specific sets of climates. The first one is the French summer climate, under which the house was competing during Solar Decathlon 2014. The other one is the Scandinavian context which is the current year-round environment of the house. This peculiarity in the design makes it worth investigating how EMBRACE performs in the two different environments. The house's performance was already evaluated by the Solar Decathlon sub-competitions in France, and the current measurement campaign extends this evaluation to the Scandinavian environment. The present article focuses on the summer period, from the 1st of June to the 30th of September 2015.

2. Description of the house and its operation

2.1. Description of the house

Figure 1. Outside views of EMBRACE in Nordborg, Denmark, from South-East (left) and South (right).

EMBRACE is a single-family dwelling of 59 m^2 floor area. It is designed to be placed on the rooftop of existing buildings of two or three stories, in the frame of a refurbishment process, in order to occupy these unused spaces and densify cities [3]. The thermal envelope of the house is covered by a second skin, a glazed envelope referred to as the Weather Shield, which protects it from rain and wind. The Weather

Shield also includes monocrystalline photovoltaic cells to produce electricity, split in two categories: opaque panels situated above the house, and semi-transparent panels situated above the sheltered garden (Figure 1, right). The total peak power of the panels amounts to 6.4 kWp, however because of several dysfunctions that occurred during the studied period, only 2.85 kWp of panels were producing electricity from June to September 2015. Part of the space below the weather shield consists of a sheltered garden, which is not actively conditioned. The house's structure is divided in four modules and its thermal envelope is highly insulated with a U-value of 0.08 W/m^2K for the walls (glasswool insulation).

2.2. Mechanical systems

EMBRACE is equipped with a dry-radiant floor system, covered with ceramic tiles, and which is the main source of heating and cooling to the space. The circuit is divided into six loops, two for the upstairs bedroom and four for the rest of the house on the ground floor. A pumping and mixing station enables to circulate the water into the floor.

A reversible air-to-water heat pump (Daikin Altherma) produces the heated or chilled water which is stored in a 800 liters tank before to be circulated in the radiant floor. Mechanical ventilation with passive heat recovery is also installed in the house (Nilan Compact P unit). The ventilation exhausts are situated in the kitchen hood, the bathroom and on the first floor level. The fresh air is supplied through two inlets at the ground floor level, and one on the first floor level.

2.3. Operation modes (heating and cooling)

The house was in cooling mode during July and August, with a cooling set-point of 24°C for the radiant floor system, and a set-point of 15°C for the leaving water from the heat pump. During the rest of the studied period (June and September), the house was in heating mode, with a heating set-point of 20°C, and a set-point of 30°C for the leaving water from the heat pump. Mechanical ventilation was set to a constant air change rate of 0.7 h^{-1} for the sole purpose of providing fresh air.

The occupancy was not controlled since the ground floor could be visited by the public during opening hours of the park. Based on CO_2 concentration and noise measurements, it is estimated that 2 visitors were present in average from 9:00 to 17:00 every day, with occasional peaks of up to 10 people during short periods of time. The access to the first floor was prohibited to the visitors. Further details of the house's structure and its systems can be found in [3] and [4].

3. Methods

3.1. Indoor climate

Operative temperature was measured by PT100 sensors mounted in Ø40 mm globes, calibrated in a climate chamber, with a resulting accuracy of ± 0.3°C. Two of these sensors were placed in the first floor, at 0.6 and 1.1 m heights. As it was not possible to place a sensor tripod on the ground floor because of the presence of visitors, one of these globe temperature sensors has been placed hanging from the first floor, at ceiling height (2.5 m from the ground floor).

Air temperature was measured either by multi-sensor modules (Netatmo, accuracy of ± 0.5°C) or by shielded PT100 sensors (accuracy of ± 0.3°C). Those sensors are placed on a tripod at the first floor at 0.1, 0.6, 1.1 and 1.7 m heights, and on two locations of the ground floor. Additionally, three surface temperature sensors PT1000 were placed on the bedroom floor to record the temperature at the surface of the tiles. All sensors' locations can be seen on the elevation of the house in Figure 2.

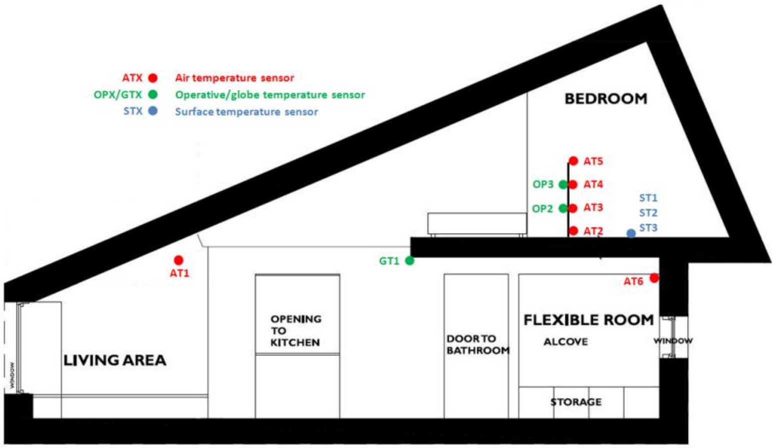

Figure 2. Elevation of the EMBRACE house with locations of sensors.

A weather station placed on the roof records the outdoor conditions (accuracy of ± 0.5°C for the air temperature, ± 3% for the relative humidity and ± 1 m/s for the wind speed). Another weather station of the same model is placed in the sheltered garden to measure the difference between the climate under the weather shield and above it.

3.2. Energy use and production

Energy use of the heat pump

A heat meter (Kamstrup Multical 302) is installed in the circuit between the tank and the radiant floor pumping station. It measures the flow with an accuracy of less than ± 5 %, and the temperature difference with an accuracy of ± (0.15+2/ΔT) % with ΔT the temperature difference between inlet and outlet. The monthly maximum heating or cooling power is also recorded by the heat meter. The monthly energy values for heating or cooling are then converted into electricity used by the heat pump, using the COP and EER values from Table 1.

The calculated COP/EER values are particularly high since the environmental conditions were favorable for the production of heated or chilled water during the summer. These values (COP = 6.4 and EER = 4.2) are utilized hereafter to convert the energy metering values into electricity use of the heat pump cycle. To this obtained value should be added the electricity use of the indoor unit, which mainly consists of the circulation pump (46 W, inverter controlled). Assuming the pump was constantly running (which is an overestimation, but a safe hypothesis), the resulting electricity use amounts to 1.1 kWh/day.

Table 1. COP and EER values of the heat pump.

Reversible Heat Pump Daikin Altherma ERLQ004-CAV3			Nominal data from the technical datasheet [5], for indication	Measured conditions from June to September
Heating	Heating capacity	kW	4.40	1.2
	Ambient temperature	°C	7	5.4 to 19.6
	Leaving water temperature (LWT)	°C	35	30 (setpoint)
	COP	-	5.04	**6.4**[*]
Cooling	Cooling Capacity	kW	5.00	0.7
	Ambient temperature	°C	35	8.6 to 30.8
	Leaving water temperature (LWT)	°C	18	15
	EER	-	3.37	**4.2**[*]

[*]Values calculated with an internal tool from Daikin, based on the mentioned conditions.

Electricity use of the Air Handling Unit (AHU)

The electrical energy use of the AHU was not directly monitored, but the power of the AHU was previously measured at 25 W when operating with an air flow rate of 29 l/s and passive heat recovery [6]. During the summer period, the mechanical ventilation was constantly operating in this mode with the same flow rate, therefore the electrical energy use of the AHU is assumed to be 0.6 kWh/day (corresponding to a power of 25 W during 24 hours).

Energy use of the radiant floor system

The electrical use of the pumping, mixing and controlling station of the radiant floor system has neither been directly measured, but Kazanci and Olesen [2] reported in this matter a rather similar case. The house they studied was equipped with the same radiant floor system (Uponor), and the floor cooling operation case (with the same set-point of 24°C) showed a maximum electrical use of 0.51 kWh/day. This value is therefore considered for the present study. These assumptions introduce some errors in the energy calculations since the setup is not exactly the same (number of loops or floor covering for instance), but they are considered safe hypothesis nevertheless.

Electricity production

The electricity production has been monitored from the inverter (Schneider Electric Conext RL). The monthly values have an accuracy of ± 0.1 kWh.

4. Results

4.1. Indoor Climate

The operative temperature measurements are displayed on Figure 3, along with the outside air temperature (because of technical issues, data loss occurred between the 25th and 31st of July). The repartition of the operative temperature between the indoor climate categories defined by EN 15251 [7] is shown on Figure 4.

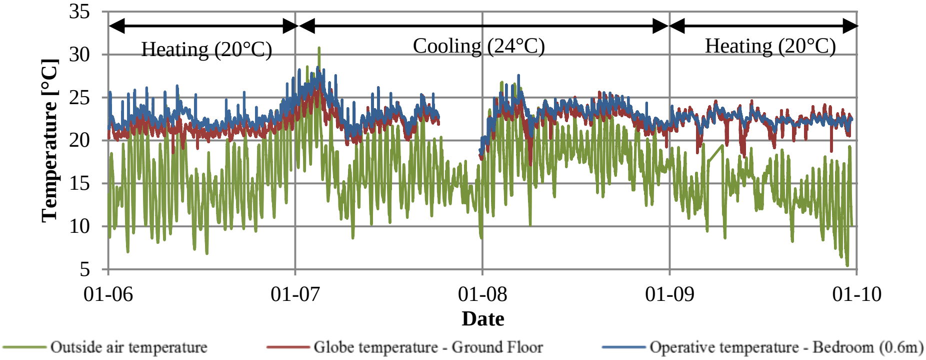

Figure 3. Operative and outside air temperature curves (June-September 2014).

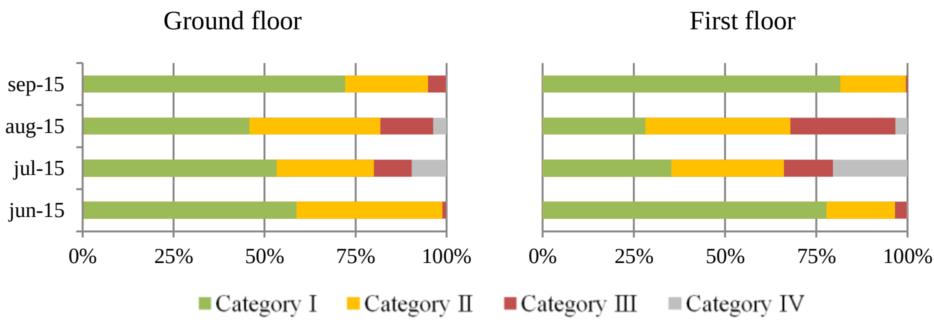

Figure 4. Repartition of the time between the different Indoor Climate Categories.

The house showed satisfactory results in terms of indoor thermal environment: the operative temperature was above 26°C for 58 hours on the first floor and for 15 hours on the ground floor during the four studied months. These values stay below the limit of 100 hours recommended by the Danish standard DS 469 [8]. Overheating did not result to be an issue, even with the effects of the second-skin envelope, but the operative temperature sometimes dropped below the heating limit of 20°C even in summer. This was caused by a combination of door openings by visitors and cold outside weather conditions.

The indoor climate was quantitatively better during the heating operation periods, than during the cooling operation period: indoor climate Category II was met for more than 95% of the time in June and September, and for more than 66% of the time in July and August. These results question the choice of operating the house in cooling mode under a Scandinavian climate. It appears that the installation of a cooling system in such a house could even have been avoided, but it should be noted that the cooling system was implemented for the house to perform under the French summer climate during the Solar Decathlon Europe 2014 competition.

The surface temperature of the floor always stayed within the range 19-29°C usually considered optimal for comfort and to avoid condensation [9].

4.2. Energy balance

For the energy balance, the electricity used by the mechanical systems (heat pump, radiant floor system, mechanical ventilation) is reported along with the electricity produced by the PV panels. For the considered four months, the house produced 1563 kWh of electricity while using 333 kWh. Figure 5 shows the monthly detailed data.

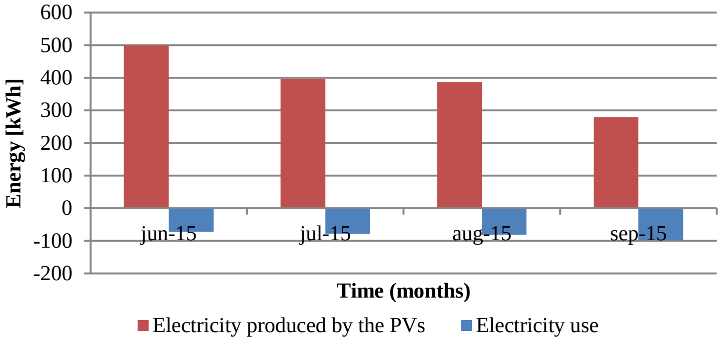

Figure 5. Electricity use and consumption during the period June-September 2015.

This energy balance only covers the summer season, and is therefore not representative of an annual evaluation which would include the large electricity use due to heating in the winter season. Nevertheless, it shows a relatively encouraging trend to achieve the positive balance of a plus-energy house when the year-round evaluation will have been completed. In fact, the total energy used during the considered period accounts for 5.6 kWh/m^2 which leaves 14.4 kWh/m^2 of energy left to be used during the other two thirds of the year, in order to achieve the target limit of 20 kWh/m^2.year electricity consumption set in the Danish Building Regulation for 2020.

The maximum cooling load observed during the summer season was 0.7 kW. This value is lower than the expected 1.3 kW estimated by simulations by Péan and Gennari [4] during the design phase. This can be explained by the fact that the house was not in normal operation: it was open to the public, and visitors could enter during the opening hours of the park where it is placed. This means that doors could have been left open, resulting in high natural ventilation rates that helped cooling the indoor space.

Additionally, no internal heat gains such as cooking activities, presence of occupants at night or use of electronic devices occurred during the measurement period, which lowered the need for cooling.

4.3. Semi-outdoor space

This study provided the opportunity to investigate the benefits of the second skin and the semi-outdoor space. A semi-outdoor space defines neither an indoor space because it is not conditioned, neither an outdoor space because it is protected from rain and wind, but a “third room” transitioning between those two areas. The sheltered garden of EMBRACE constitutes such a space: the weather shield enables to make its environment more comfortable than outdoors as well as to reduce the winter heating consumption [10,11].

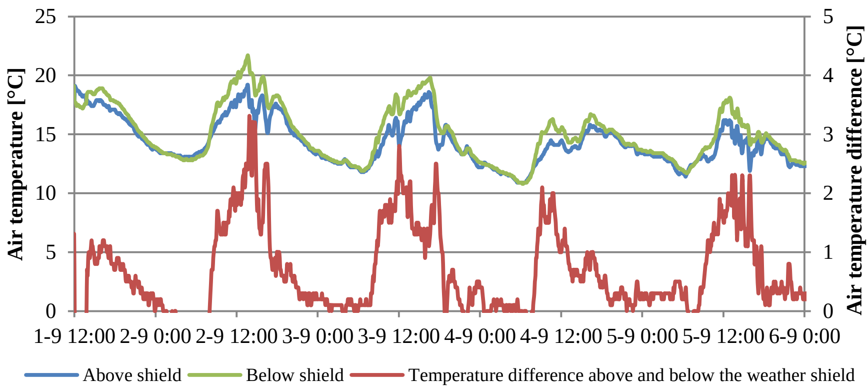

Figure 6. Temperature difference between above and below the Weather Shield.

By the means of the two weather stations placed above and below the weather shield, it was possible to measure the influence of the glass cover on the climate of the sheltered garden. It was observed that 70 to 80% of the incoming solar radiation is blocked by the weather shield, and particularly by the integrated opaque photovoltaic cells. The remaining 20 to 30% enable to heat the sheltered garden space by a few degrees. Part of the heat absorbed by the glazed weather shield is redistributed to the sheltered garden by radiation and convection and therefore also participates in raising the temperature in this space. An example is given in Figure 6, with data from the 1st to the 5th of September 2015. Even though the garden is neither conditioned nor totally closed, the air temperature frequently reaches 2 to 3°C higher than outdoors during daytime. This enables to use the semi-outdoor space during a longer part of the year, and therefore to increase the usable space of the house (which was designed relatively small for this reason)[10,11]. This design strategy is particularly adapted to cold climates because the second-skin could result in overheating in warmer climates.

5. Discussion

The reliability of the present evaluation could be questioned since the house was not operating in normal conditions. Implemented inside a science-themed park, EMBRACE was visited by school classes and the general public, but not truly inhabited. The resulting heat gains were less regular than if a family had lived in the house, and the natural ventilation was increased because of random door openings. However, most indoor climate measurements took place on the first floor where the visitors' access was prohibited. Furthermore, this situation did not affect the production of electricity among other parameters, and it still gives a fair indication of the systems' ability to provide a satisfactory indoor environment. This issue is resolved for the upcoming winter evaluation of the house, because the park will be closed, therefore thermal manikins can be installed to simulate occupancy, and visitors will not disturb the measurements. The results from the winter evaluation will be reported at a later stage, and they will draw more global conclusions on the overall annual performance of the house.

Because of unavailable measurements, some results relied on assumptions, especially concerning the energy use of the mechanical systems. The authors have tried to take all necessary precautions when making these assumptions, always choosing the less favorable case to stay on the safe side (i.e. overestimating the energy use).

The evaluation shows that the functioning of the mechanical systems could be further improved. The possibility of actively cooling the house is not justified, and neither is the presence of the storage tank for the heated or chilled water (NB: those two options were implemented to perform optimally under the French summer climate). The mechanical ventilation could have been operated intermittently to decrease its energy use when the occupants are not present. Taking into account these counter-performances, the systems still performed in a satisfactory way.

6. Conclusion

The EMBRACE house has been evaluated under the summer conditions of Nordborg, Denmark, from June to September 2015. Results show that the house was able to provide a satisfactory indoor climate, with the operative temperature staying for a minimum of 66% of the time within Indoor Climate Category II during the cooling period, and a minimum of 95% during the heating period. Overheating did not result to be an issue with 58 hours above 26°C on the first floor (15 hours on the ground floor), which questions the necessity of a cooling system. The climate of the sheltered garden presented an air temperature frequently higher than the outside air temperature by 2 to 3°C, even though this space was neither totally closed nor conditioned. In addition to the protection from wind and rain provided by this space, these results show that it is possible to occupy it during a larger part of the year, extending the available space provided by the house.

EMBRACE performed as a plus-energy house during the studied period, with a positive energy balance: 1563 kWh of electricity were produced by the PV panels, and 333 kWh were used for the functioning of the house. These results over a summer period of four months should not be considered separately from the rest of the year if the aim is to draw up an annual energy balance. The upcoming annual evaluation will assess if the energy balance remains positive when taking into account the winter period. However, the observed trend shows that the house could effectively perform as a plus-energy building over the course of one year.

Acknowledgments

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References

[1] M. Maivel et al.(2015). Status on the Ground - Overview of existing surveys on energy performance related quality and compliance. QUALICHeCK Project Report.

[2] O. B. Kazanci and B. W. Olesen (2014). Sustainable Plus-energy Houses – Final report. Technical University of Denmark, Department of Civil Engineering. 50p.

[3] Team DTU (2014). Solar Decathlon 2014, "Embrace: Delivery 7 Project Manual".

[4] T. Q. Péan and L. Gennari (2014). Conditioning of a plus-energy house using solar systems for both production of heating and nighttime radiative cooling. Technical University of Denmark, Department of Civil Engineering.

[5] Daikin Europe N.V. (2015). Daikin Altherma – Low temperature split, Installer reference guide.

[6] R. Haagensen (2014). Hybrid residential ventilation for DTU Solar Decathlon 2014. Technical University of Denmark, Department of Civil Engineering.

[7] EN 15251 (2007). Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Brussels: European Committee for Standardization.

[8] DS 469 (2013). Heating and cooling systems in buildings. Copenhagen: Danish Standards.

[9] EN 1264-2 (2008). Water based surface embedded heating and cooling systems – Part 2: Floor heating: Prove methods for the determination of the thermal output using calculation and test methods. Brussels: European Committee for Standardization.

[10] K. Foteinaki et al. (2016). Structures with a Semi-Outdoor Space: Energy Performance. Submitted to 12th REHVA World Congress CLIMA.

[11] C. Papachristou et al. (2016). Structures with a Semi-Outdoor Space: Thermal environment. Submitted to 12th REHVA World Congress CLIMA.